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# What Is the Metaphysics of Science?

Stephen Mumford and Matthew Tugby

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## 1. The emergence of modern metaphysics of science

The label ‘metaphysics of science’ is one that has come to be used to refer to a philosophical sub-discipline that has been gaining momentum for roughly forty years. The emergence of this sub-discipline has been made possible by the (perhaps partial) recovery of metaphysics from the blow dealt to it by the Neo-Humean empiricist movements of the first half of the twentieth century. Without this recovery, not only would the metaphysics of science be non-existent as a discipline, the term ‘metaphysics of science’ would come close to being an oxymoron. The reason for this is that according to the aforementioned empiricist views (for example Carnap 1935, Ayer 1936 and Schlick 1938), metaphysical statements have little meaning because, unlike the statements of natural science, they are typically neither analytic nor *a posteriori*. On this view, the metaphysics of science becomes a discipline in which philosophers ultimately say meaningless things about natural science, which is itself characterised (in part) by the fact that it is meaningful above all other disciplines. Clearly, this would make the metaphysics of science pointless in a way that is ironic.

Fortunately, many of the concepts and debates which were cast into the bonfire by these radical empiricist movements have regained currency, and even if there is much disagreement between metaphysicians of science on the issues they debate, there is at least an assumption that philosophers can have meaningful debates about such issues. The main aim of this chapter is to try

to identify in general terms what those issues are. More precisely, we will address the following two questions amongst others. First, what do the various debates falling within the metaphysics of science have in common, if anything? Second, what distinguishes a question within the metaphysics of science from questions in other areas of metaphysics?

Answering the above questions is no easy task, but as a way of beginning to illustrate the sorts of debates that take place within the metaphysics of science, let us say a little about the debate on whether science supports the view that there are necessities in nature. This is an appropriate starting point for two reasons. First, the concept of necessity in nature is the kind of metaphysical concept that the Neo-Humean empiricists described above were arguably sceptical of above all others. Second, the point at which philosophers began to take a renewed interest in the debate concerning necessity in nature arguably marked the point at which the modern discipline of metaphysics of science began.

The main reason why empiricists had been so hostile towards metaphysical concepts, such as that of natural necessity, is that these concepts were not thought to be sufficiently grounded in experience. If a concept is not grounded in some aspect of experience, then it was thought to be rendered utterly mysterious and insignificant. If notions of natural necessity have any meaning at all, the Humean empiricists say, this is only because we have an internal (observable) feeling of inevitability which attends our observations of the regularities in the world. But such a feeling, existing as it does in the mind, is not what the notion of natural necessity was initially intended to capture.

Now, one way of questioning these empiricist conclusions is to question the strict separation between metaphysical *a priori* statements on the one hand, and scientific *a posteriori* statements on the other. If one can successfully argue there to be a more subtle and complex relationship between metaphysical and scientific statements, one which allows there to be an interplay between metaphysics and natural science, then perhaps the empiricists' anti-metaphysical conclusions can be avoided. In the 1970's, these kinds of arguments did indeed start to emerge. At this time, there was a general feeling that science itself might support certain metaphysical claims, and in the other direction it was thought that scientific statements might themselves rest in some way on various metaphysical assumptions. The former point was strikingly made by Kripke (1972) and Putnam (1973) in the aforementioned debate about necessities in nature. Not only did they argue there to be metaphysical necessities concerning natural kinds, such as that water is necessarily the compound H<sub>2</sub>O, but they argued this to be a form of *a posteriori* necessity; a kind of necessity that is revealed at least in part through scientific observation.

Kripke and Putnam's work arguably provided the springboard for debates about natural necessities in other aspects of nature. In 1975, Harré and Madden published a now too-little-discussed book in which they argued for a thoroughly anti-Humean metaphysical outlook, in the light of science, on which nature is seen to be full of causal powers bringing causal necessities to the world. This has since led to the development of many other causal power ontologies, such as those of Shoemaker

(1980), Cartwright (1999), Martin (1993), Ellis (2001), Molnar (2003), Mumford (2004) and Bird (2007). Interest in the causal variety of metaphysical necessity also led, in part, to new work on the related concept of lawhood, a concept already employed pervasively in natural science. Metaphysicians of science began to wonder whether, if we can have justified beliefs in other kinds of metaphysical necessities, there might be reasons also for taking scientific laws to be necessary. If so, then what grounds this necessity? If the laws are merely contingent, then what, if anything, explains the continuance of the laws? These questions were attracting new interest from metaphysicians of science, and one of the first full length studies on the issue of lawhood came in 1983 with the publication of Armstrong's *What is a Law of Nature?*. Since then, the topic of lawhood has been at the heart of the discipline, along with those relating to the aforementioned notions of kindhood and causation.

We do not wish to give the impression from what has been said thus far that all metaphysicians of science agree that scientific discoveries (or the very existence of science itself) support beliefs in metaphysical necessities of various kinds. On the contrary, there are many metaphysicians of science who can be said justifiably to be Humean in spirit. Such philosophers tend to claim that science is neither underpinned by, nor lends support to, metaphysical necessities relating to kindhood, lawhood and causation. What is clear, however, is that their engagement in these very issues shows that they think there are meaningful debates to be had in the area of metaphysics of science. This in itself, as we have tried to suggest, has marked a significant development in philosophy.

We also do not wish to give the impression from what has been said so far that debates surrounding the issue of metaphysical necessity are the only debates within the metaphysics of science. But this general debate does provide a good illustration of how the feeling has emerged in some quarters that there is a mutual dependence between metaphysics and natural science. As we have suggested, the strong empiricism of the early twentieth century is typically now thought to be too radical and naive in its treatment of metaphysics. Likewise, an extreme rationalistic 'armchair' form of metaphysics, which does not engage with the current discoveries of science, is also thought to be misguided. There is an increasing feeling that the best scientists and metaphysicians are those who talk to each other.

Before beginning our search for a more detailed definition of the metaphysics of science, it is worth mentioning a more recent trend within modern metaphysics of science, one which has emerged during the past decade or so. This is the project of system building. As has been briefly indicated already (and as will be shown further as the chapter proceeds), the core scientific concepts of kindhood, lawhood and causation are interrelated, and this has led some philosophers to attempt to build ontological systems which can simultaneously account for the nature of kindhood, lawhood and causation. These systems can even be seen as attempts to underpin the entire body of scientific statements, bearing in mind that scientific statements typically relate in some way to kinds, laws or causal facts. This 'underpinning' is often described in the now popular terminology of truthmaking. The modern system builders have been concerned with what it is that makes scientific statements

true. What is it, for example, that makes it the case that a scientific law either does or does not hold? Various answers seem possible, or at least imaginable, which indeed explains why there are debates to be had within the discipline of metaphysics of science. This also indicates, in part, what was wrong with the radical empiricists of the first half of the twentieth century. Whilst these empiricists rightly took scientific statements seriously, they did not ask in virtue of what these statements might be true, overlooking important philosophical issues as a result.

Answers that current system builders have given concerning the metaphysical underpinnings of science have varied considerably. Ellis (2001), for example, has argued that our total body of scientific statements can only be accounted for if we accept a metaphysical system containing six fundamental ontological categories. E.J. Lowe (2006), in contrast, argues that only his four-category ontology provides an adequate metaphysical foundation for natural science. Heil (2003) is more parsimonious still, arguing for a two-category ontology. The debates between the system builders within the metaphysics of science are ongoing. But again, the very existence of these debates shows that the presuppositions which have led to the emergence of the metaphysics of science remain, and that the discipline is in a state of health.

## 2. The beginnings of a definition

So far, we have identified some of the metaphysical-cum-scientific concepts that metaphysicians of science are concerned with: natural kinds, laws, causation and causal power. This immediately gives us a sense of what the metaphysics of science, as the term is now commonly used, *is not*. One obvious interpretation of the metaphysics of science could be that it is the study of specific metaphysical debates as they arise within specific scientific sub-disciplines. A notorious example is the debate concerning absolute versus relative conceptions of space, which was contested for example by the Newtonians and Einsteinians. Whilst this is a metaphysical debate which has been scientifically informed, this is not the kind of debate with which contemporary metaphysicians of science are typically concerned.<sup>1</sup> They are rather concerned with debating the more *general* scientific-cum-metaphysical concepts, concepts which are deployed in *all* the natural sciences, including the special sciences. Chemists, for example, speak of chemical kinds and properties, and chemical laws concerning those kinds and properties. Biologists speak of *their* own biological kinds and laws. Psychologists identify psychological laws, and so on. In contrast, the concepts of, say, absolute and relational space, are not common to all the sciences: they are specifically concepts developed within the discipline of physics. This point shows again how the system-builders within the metaphysics of science are extremely ambitious: they claim to offer a metaphysical system which can underpin *all* branches of natural science.

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<sup>1</sup> This is not to say that papers on metaphysical issues in specific branches of science do not sometimes fall under the heading of 'metaphysics of science' in conferences, for example. Our point is just that such papers are not at the core of the discipline as we understand it.

There are also other ways in which the term ‘metaphysics of science’ could be taken by someone not familiar with the history of the discipline. One could think, for example, that the term ‘metaphysics of science’ refers to metaphysics in general, whilst conveying a sense that metaphysics should not depart too far from the concerns and discoveries of current science. Several current philosophers hold this kind of view, showing hostility to what we might call the ‘armchair metaphysicians’ who do not make an effort to engage with current science (see e.g. Ladyman & Ross 2007). It is clear, however, that this agenda is orthogonal to the concerns of those within the discipline of metaphysics of science. Those interested in studying the central metaphysical concepts within natural science *may or may not* disapprove of more abstract metaphysicians who think about issues which are less obviously connected with the subject-matter of current science.

It is fairly clear, then, what the discipline of metaphysics of science *is not*. But can we say anything more insightful than merely identifying the kinds of concepts which metaphysicians of science investigate? Is there a common theme or aim running through each of the debates within the metaphysics of science? If the answer is yes, then a general definition of the discipline should be achievable, and such a definition may well be philosophically illuminating. It may, for example, reveal something about the essential nature of science itself.

We believe that there is a common theme and aim running through each debate within the metaphysics of science, and the aim of the remainder of this chapter will be to begin to uncover it. However, the definition we will arrive at will have to be vague in some respects. To aim for an exact definition would be unrealistic for a chapter-length piece, for reasons we will shortly explain. But regardless of how the precise details of the definition are to be spelled out, we hope that the general insights we offer will be clear and justified.

One of the problems regarding the delineation of the metaphysics of science is that the definition of science is itself a matter of philosophical controversy. Some are even sceptical as to whether a sharp criterion for distinguishing science from non-science is possible (see for example Feyerabend 1975). The fact that there is an ever-increasing range of aims and methods within the various scientific disciplines lends weight to this scepticism. Philosophers cannot even agree on what kind of general entity science should be classified as. It has been taken at one time or another to be a set of statements, a set of propositions, a tool, a method, a research activity, an ideology, a research network, a research institution and even a philosophy, to name but a few proposals.

There is however some agreement on what science is not. The radical empiricist view of science, mentioned earlier, now has few adherents. According to that view, science is distinguished by the fact that it is the only respectable discipline, as it is constituted by a set of statements which, unlike metaphysical statements, are meaningful. More precisely, scientific statements are said on this view to be meaningful insofar as they are either analytic (such as logical truths), or synthetic, which is to say they are verifiable in some way through empirical observation. However, formulating a synthetic

principle of verifiability in a satisfactory way proved extremely difficult, not to mention the fact that the very distinction between the analytic and synthetic was shown to be questionable (see Quine, 1951). Each formulation of the proposed principle was subject to counterexamples, modified versions were subject to further counterexamples, and so on.

These complaints led to a move away from trying to capture the nature of science in terms of the notion of verifiability. Famously, for example, Popper claimed that what is important and unique to science is not verifiability, but *falsifiability*. What distinguishes a genuine science from, say, astrology or Freudian analysis, according to Popper, is that its claims can be *falsified* by experiential anomalies. Science is risky. But this characterisation also came with problems. As Lakatos (1978) and Thagard (1978) point out, scientists do not automatically abandon their core theories when an evidential anomaly occurs, nor should they. Rather than accepting that their theories are false in light of recalcitrant observations, scientists look for alternative explanations for the anomalies, by questioning the reliability of their testing methods or questioning the auxiliary hypotheses which, in conjunction with the core theory, entail that the data in question is indeed anomalous. Furthermore, argues Lakatos, it is a good thing that scientists proceed in this way, for falsification strategems lead to overhasty rejections of sound theories (1978: 112).

The above line of argument suggests that science involves, in part, finding ways of explaining new facts and ‘anomalies’ that arise (see also Thagard, 1978). Criticisms of previous demarcation criteria also led Lakatos and others to propose a further plausible distinguishing feature of genuine science. What genuine, progressive sciences have in common is that they predict facts, many of which are *novel* (1978). Popper appears to agree on this point also. (Popper’s view merely differs on the issue of what scientists should do when the novel predictions *go wrong*). For example, Popper presents Einstein’s gravitational theory as a paradigm case of a genuine scientific theory giving novel and strikingly precise predictions (as opposed to non-scientific theories which, according to Popper, are typically compatible with any outcome, such as Adlerian psychology and the Marxist theory of history (1957)). Einstein’s theory implies, for example, that light is attracted to very heavy bodies. This idea had not occurred to physicists before, nor did it seem to have any *prima facie* plausibility. Now, a consequence of this idea was that the light from a star whose apparent position is actually quite close to the sun would travel in such a direction that, to us, the star would appear to be slightly shifted away from the sun. Using data taken during a daytime eclipse, which allowed the stars close to the sun to be visible, it was discovered that Einstein’s prediction was indeed correct (Popper, 1957). As Popper points out, this prediction was highly novel and also risky: had the star appeared not to have moved, or to have moved to a lesser or greater extent than expected, the theory would have been embarrassed. But given this highly novel prediction was accurate, Einstein’s theory was shown to be an instance of genuine, impressive science<sup>2</sup>.

<sup>2</sup> Note that although Einstein’s theory superseded Newtonianism, this does not detract from Newtonianism’s status as a genuine science, for it too made outstanding novel predictions, as Lakatos explains (1978). For example, contrary to the dominant views of comet motion, Newton’s theory entailed that some comets

We take it that for all the disagreements over the details of the correct definition of science, there are some general distinguishing features of science which most in the demarcation debate can agree on. Regardless of whether science is best understood as a set of statements or propositions, or say a research activity, what distinguishes a genuine science from mere pseudo-science, amongst other things, is that it makes predictions (many of which are novel), and provides explanations for new facts and anomalies. It is these main features that we will take into account in formulating our definition of the metaphysics of science. There is, of course, much more to be said about the demarcation of science, but the kind of demarcation criteria identified, rough as they are, will be sufficient to allow us to get across our main points concerning the metaphysics of science.<sup>3</sup>

Taking into account the features of science we have identified thus far, and taking into account earlier comments, we may propose the following definition of the metaphysics of science, which we can then proceed to build upon:

**MOS def\*\*:** The philosophical study of the general metaphysical notions that are applied in all our scientific disciplines, disciplines which offer novel predictions and provide explanations of new facts and anomalies within their given domain.

Now, a question one might ask about the presence of these metaphysical notions in all scientific disciplines – such as those of kindhood, lawhood, causation and causal power – concerns whether it is an *accident* that these concepts are central to all of science. Our view is that it is not, and an exploration of why this is so will further our understanding of the nature of the metaphysics of science.

The claim that it is not accidental that the notions of kindhood, lawhood, and causation are at the heart of all the sciences suggests that without kinds, laws and causation, science as we know it would not even be possible. Given our partial definition of science, this is to say that without kindhood, lawhood and causation, *neither systematic scientific predictions nor explanations would*

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moved in hyperbolas, and others in parabolas. Using Newton's theory, Halley predicted that a certain comet (now called 'Halley's Comet', of course) moved in the former way, and that it would return in seventy two years time. Seventy two years later the comet did indeed return, and this took the credibility of Newton's theory to yet further levels.

<sup>3</sup> Classificatory work, for example, might also be said to be at the heart of natural science. It could be argued, however, that even this activity is not independent of that of providing predictions and explanations, since for example certain natural kind classifications have to be made before many laws can be formulated. In any case, as stated above, in order to make the main points of this chapter we do not require a more precise demarcation of science than that offered here.



*be possible*. This is a thought we find plausible, as will be explained in the following sections. This thought also indicates why the metaphysics of science has developed in precisely the way it has, i.e., as primarily an investigation into the nature of kinds, laws, and causation.

This modal suggestion, that the metaphysics of science is an investigation of the metaphysical preconditions of science, has rather a Kantian flavour. But arguably, the idea that certain metaphysical phenomena are necessary for science was present in ancient thinking, as we will now see.

### 3. Ancient metaphysics of science and the modal claim

The well known Platonic theory of forms (or ‘ideas’) is an early example of an ontological theory of kinds. As well as the physical realm of mutable particulars, there is, according to Plato, a non-physical transcendent realm of immutable kinds, which the physical particulars instantiate. Since Plato proposed his theory, a significant number of metaphysicians have continued to advocate kind ontologies of various sorts (see for example Ellis 2001, Lowe 2006), although most modern metaphysicians tend to avoid the claim that kinds exist in a transcendent realm.

Now, in his *Metaphysics*, Aristotle refers to a number of arguments in support of the ontology of forms that he was aware of from the Platonic schools. Interestingly for our purposes, one of these is an argument from science, and this is perhaps one of the first exercises within the metaphysics of science. As Melling writes, the argument is described by Alexander as being, roughly, that ‘[I]f the sciences have any validity, if they can attain knowledge, then there must be a realm of immutable, intelligible realities which are the true objects of knowledge’ (1987, p.117). The argument thus takes us from the existence of science, and in particular the generalisations it gives rise to, to the thought that there must be objects of a kind which makes the activity of science, and specifically scientific knowledge, possible. Alexander articulates this thought in connection with medicine and the rational science of geometry:

‘... if medicine is not a science of this particular health but of health simply, there will be a certain health-itself; and if geometry is not a science of this particular equal and this particular commensurate, but of equal simply and the commensurate simply, there will be a certain equal-itself and a commensurate-itself; and these are the Ideas”  
(Alexander, *Metaphysics Commentary* 79.3-88.2)

The key insight here is clearly that science typically deals not with facts about particulars but rather facts of a more general character, or as Alexander puts it, of a simple character. This is to say that science typically tells us about the nature of *kinds* of individuals rather than specific individuals. To use examples from Alexander’s themes of medicine and geometry, the scientists might say for example that ‘penicillin cures Lyme disease’ or that the ‘square of the hypotenuse equals the square

of the opposite plus the square of the adjacent'. These statements are about Lyme disease *in general* and right-angled triangles *in general*.

Now, importantly for our purposes, the Platonic argument from science has a modal force to it: given the nature of scientific knowledge, specifically its general character, the world needs to be such-and-such a way metaphysically. We may of course think that the Platonists overstep the mark in thinking that the nature of science leads us directly to the theory of forms. Whether irreducible kinds (not to mention transcendent kinds) provide the most plausible truthmakers for kind generalisations is a matter of ongoing controversy. Nevertheless, the general question of what the world needs to be like (metaphysically speaking) in order for science to be possible and scientific claims to be true, is one that we take to be insightful, and one that actually lies at the heart of the metaphysics of science, if only implicitly.<sup>4</sup> One reason for thinking that this latter point holds is that it provides an explanation as to why the specific subject matter of the metaphysics of science is as it is. Let us explain.

We have already highlighted that the key debates within current metaphysics of science concern the natures of kindhood, lawhood, causation and causal powers,<sup>5</sup> but as mentioned in the last section, there remains a question about *why* these are the core topics of the discipline, aside from the fact that they are concepts which are found in all branches of science. Our discussion of Platonic metaphysics of science has suggested a possible explanation, and one which we find plausible: kinds, laws, causation and causal powers (whatever their metaphysical natures may turn out to be), are precisely what make scientific enquiry as we know it possible. Bearing in mind our earlier comments about the nature of science, this is to say that the aforementioned phenomena are those which make scientific predictions and explanations possible. In the next section, we will explore the main reasons for accepting this modal aspect of the metaphysics of science.

#### 4. Order in the world

A world in which there are kinds, laws and causal powers is a world in which there is *order*. In such worlds, certain causal dispositions or powers are associated with certain natural kinds, a relationship which may be expressed by some of the natural laws. An example of such a relationship is that expressed by the law 'electrons are negatively charged' or 'salt dissolves in water'. Because of the general character of such laws, they tell us what causal dispositions we can expect from any *instance*

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<sup>4</sup> We accept that many will find this to be quite a strong claim, and so it is worth pointing out that most of the points to follow stand even if one takes the metaphysics of science to have the more modest aim of investigating what the world *could* be like in order for science as we know it to arise. (Thanks go to an anonymous referee for this point.)

<sup>5</sup> Talk of causal powers has an anti-Humean flavour, but we do not intend the term 'power' to be metaphysically loaded (i.e., we are not ruling out here that powers are to be understood in some reductionist sense),

of the kind in question. When we encounter a new electron or a new piece of salt, we do not have to perform tests to determine whether that particular electron is negatively charged or that particular salt is soluble. The law alone tells us what to expect, and the law is made possible by the natural-kind structure of the world and its relationship with the causal dispositions.<sup>6</sup> In a chaotic, disorderly world in which there are no natural kind structures, and in which events occur entirely randomly, there would not be the patterns in nature that are required for there to be natural laws<sup>7</sup>.

Now, it seems plausible that within this chaotic, disorderly world, it would not be possible to make the kinds of predictions (not to mention *novel* predictions) or construct the kinds of explanations that we find in natural science.<sup>8</sup> Scientific predictions concern what will happen to certain entities, and in order to begin formulating a scientific prediction, we ask what kinds of thing those entities are. We then consider which causal dispositions things of those kinds have. Once we have established this, we can then identify the causal laws (typically functional laws) relevant to those causal dispositions. Finally, we can feed the specific data we have about the relevant entities into the relevant causal law(s), thereby generating data about what will happen to those individuals at certain points in time. In short, then, the facts about kinds and causal powers, facts which the laws can capture, enable scientists to deliver the kinds of systematic predictions that they do and to do so in a strikingly efficient way.

This is not to say that, in our world, determinate predictions will always be possible (or even possible at all). For example, there are reasons for thinking that the causal powers at the level of quantum mechanics are indeterministic or 'chancy', which is reflected in the fact that the best laws we have in that domain are probabilistic. As such, any predictions based on those laws can only deliver probabilities about the outcomes. But such predictions are nevertheless useful, and certainly better than anything we could hope for in the disorderly world described earlier. A world involving probabilistic laws is one in which the future possibilities are narrowed down to quite a considerable degree. In contrast, a disorderly world is one in which anything goes: the future possibilities are not constrained in any way. A disorderly world should not therefore be confused with a 'chancy' world. A chancy world, unlike a disorderly one, is a scientific world.

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<sup>6</sup> The precise nature of this relationship is itself a matter of ongoing debate in the metaphysics of science (see for example, Bird (2001) who argues that salt dissolves in water as a matter of metaphysical necessity. See also replies by Beebe (2002) and Psillos (2002), who argue the relationship between salt and solubility is contingent (yet regular)).

<sup>7</sup> One may doubt whether this kind of world is *physically* possible. This question does not matter for our purposes. We can at least say that such a world is metaphysically possible.

<sup>8</sup> Perhaps in some minimal sense we could try to make predictions in a chaotic world, if, say, a certain particular happened to behave in a regular way over a given period. It seems clear, though, that in such a world we would not be able construct the kinds of stable and systematic predictions which natural science delivers.

The modal point holds equally for the process of explanation. Let us consider the most common form of explanation: causal explanation.<sup>9</sup> To say that an event or fact, call it X, is explained by Y is to say that Y is responsible for X, the paradigm case being where X is caused by Y. Notice, however, that in the chaotic world described above, which is void of kindhood and causation, nothing could be held responsible for anything else. Things would just happen, randomly, for no reason at all. For any given event that occurred in that world, all we could say about it is simply that 'it just happened'. But it is doubtful that this is an explanation at all, and it is certainly not a scientific explanation.

The precise nature of the phenomena that impose order on the world and allow science to be possible is a matter of ongoing debate, and our intention has not been to address any of the specific debates concerning the metaphysics of these phenomena. What we have tried to indicate, however, is how and why the study of kindhood, lawhood, causation and causal power are at the heart of the metaphysics of science. The reason is that it is precisely these phenomena which bring order to the world, and it is therefore the job of the metaphysician of science to find out just what kinds, laws, causal powers and causation amount to ontologically. In short, then, the metaphysics of science is the metaphysics of *order*.

Taking into account the insights of the last two sections, we are now in a position to adjust our definition as follows:

**MOS def\*:** The metaphysical study of the aspects of reality, such as kindhood, lawhood, causal power and causation, which impose order on the world and make our scientific disciplines possible (that is, disciplines which are able to provide predictions (often novel ones) and offer explanations for new facts and anomalies within their given domain).

## 5. The relationship between scientific disciplines

Finally, there is one important aspect of the metaphysics of science which we have not yet addressed, and one which we must now build into our definition. Earlier we saw how the various branches of science – physics, chemistry and biology, for instance – are similar in that they all trade on the notions of kinds, laws, and causation. But there are clearly considerable dissimilarities between the various branches of science. Physicists posit very different kinds of entities to, say, the

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<sup>9</sup> Etymology suggests a very close relationship between explanation and causation. When we say Y explains X, we say X because Y: notice the *cause* in *because*. However, whether causal explanation is the *only* respectable kind of explanation is a matter of controversy. For example, according to one influential account of explanation – the deductive-nomological view (see Hempel 1965) – it is the laws which play an essential role in scientific explanation. But there is no need to address the details here, for that view is also consistent with our general thesis that world-order is a precondition of explanation (- laws being an essential aspect of world-order).

chemists or the biologists, and as a result their laws look very different to those of the chemist or biologist. The differences are more striking still in the case of the 'higher-level' sciences such as psychology. What are we to make of these differences? What does the existence of a multitude of scientific disciplines, and their diversity, teach us metaphysically? Some have suspected that the differences are ultimately superficial, and that in principle the physicists could explain all of the entities and laws of the other sciences using the language of physics. This is the reductionist stance. It is, however, far from obvious that attempts to reduce all scientific claims to physics can ever be successful. For one thing, physicists who have previously attempted such reductions have encountered immediate hurdles. Take chemistry, for example. Whilst the laws of chemistry can in principle be derived from the laws of quantum electrodynamics, it seems this can only be achieved if certain information describing suitable *chemical* conditions is first fed into the equations (for further discussion see Gell-Mann, 1994). The prospects for explaining away chemical facts using only the concepts found in physics are not as bright as some had assumed.

Might it be, then, that the existence of the diverse branches of science tells us that reality is layered, with each distinct level containing unique kinds of entities and laws? To think in this way pushes us towards a view known as emergentism. But this view has also been shown to face difficulties, and so it may be that we ultimately need a middle position, one that allows scientific disciplines other than physics to be legitimate in their own right, but without completely cutting them off from each other, and particularly not from physics. Needless to say, this issue is a matter of ongoing debate. What is important from our perspective is merely that the domain of the metaphysics of science seems to be the best arena for this debate. Scientists tend to specialise in their own branches of science, each with their own concerns. Even if scientists are interested in these broader questions about how the branches of science relate, which surely the most curious scientists are, it is beyond their remit to spend large amounts of time thinking about them. Their primary job as scientists, we have suggested, is to develop theories which have great systematic predictive and explanatory power. In order to tackle the broader philosophical questions, it is necessary to take a step back from any specific scientific practice, and as philosophers, metaphysicians of science are well positioned to do this.

There is also perhaps a deeper reason why investigating the relationship between different branches of science falls naturally within the remit of metaphysics of science. We have claimed that the metaphysics of science is the metaphysics of order. And it seems clear that in investigating the relationship between the different sciences, we are likely to learn something about the order of world in terms of how it is fundamentally layered. Or if, for example, a strong form of reductionism is true, we may find that the natural world has just one layer, and that the order found in the special sciences is derived from the order found in physics (assuming physics is the reduction base).<sup>10</sup>

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<sup>10</sup> Thanks go to an anonymous referee for highlighting this important point.

Taking into account this aspect of the metaphysics of science, we may now propose our final definition:

**MOS def:** The metaphysical study of the aspects of reality, such as kindhood, lawhood, causal power and causation, which impose order on the world and make our scientific disciplines possible (that is, disciplines which are able to provide predictions (often novel) and offer explanations for new facts and anomalies within their given domain), and also the study of the metaphysical relationship between the various scientific disciplines.

## 6. The Acid Test

As a way of testing the adequacy of the definition proposed, we should consider whether it successfully marks off questions falling within the metaphysics of science from other metaphysical questions. The metaphysics of science, we have claimed, is the metaphysics of world-order. We must therefore consider whether the metaphysical issues falling outside of the metaphysics of science are independent of questions relating to the existence and nature of world-order. We suggest that they are.

There are many branches of metaphysics, each of which concern different aspects of reality. It would be unrealistic for us to try to survey all the branches of metaphysics and the questions they involve. We can, however, provide a partial list of the core sub-disciplines of metaphysics, and briefly consider whether the debates in those sub-disciplines are largely independent of issues relating to what we have called world-order. Here are some of the main sub-disciplines: the metaphysics of particulars; the metaphysics of properties; the metaphysics of time; the metaphysics of space; the metaphysics of composition; the metaphysics of identity; the metaphysics of parthood; the metaphysics of persistence; the metaphysics of numbers; the metaphysics of propositions.

We do not think it takes a large amount of reflection to see that the core questions within these sub-disciplines are indeed independent of questions relating to the metaphysical nature of world-order. We take this to show that even though our definition may be vague in some respects, it is along the right lines.

Let us briefly consider the first few items on the list. First, let's take the metaphysics of particulars, which is a classical metaphysical topic. Are particulars made up of substances, which properties hook onto, or are particulars merely bundles of properties? This question is, we suggest, independent of the metaphysics of world-order. Consider the chaotic, disorderly world discussed earlier. Particulars could exist in this world, as well as a scientific world, and so questions concerning the metaphysics of order do not have much, if any, bearing on this sub-discipline.

Take another core topic in classical metaphysics: the metaphysics of properties. Are properties best thought of as universals, tropes, or otherwise? Again, answers to this question do not seem to be constrained by facts concerning world-order. There seems no reason why entities such as tropes and universals should only exist in an ordered world. Furthermore, the trope versus universals debate can be had independently of the various debates concerning the metaphysics of order. Both realists and reductionists about causal dispositions can, for example, be either trope or universals theorists (see for example Molnar (2003) who is a trope realist about powers and Ellis (2001) who is also a powers realist, but prefers a universals view). This is not to say, of course, that metaphysicians of science are not also interested in the metaphysics of properties.

Let us now briefly consider the metaphysics of time. The core question within this discipline concerns whether time is best conceived as the A-series or B-series. Again, this question is independent of issues of world-order. Time could exist in an order-less world, and the various views about the metaphysics of ordered worlds appear to be compatible with both the 'A' and 'B' theory of time.

Finally, let us briefly consider the metaphysics of space, the central question of which is: is space absolute or relative? As we saw earlier in the chapter, this metaphysical question is one which scientists have debated, but it is not a primary concern of metaphysicians *of science*. This is because the outcome of this debate is independent of the metaphysical questions about world-order. The existence of kinds and laws, for example, are conceivable on either the absolutist or relationalist conceptions.

Due to space constraints, we will not continue to go through each item on the list. We hope, however, that we have said enough to indicate that the prospects for passing the acid test are good, and that, upon reflection, debates outside of the metaphysics of science can be seen to lie outside of the metaphysics of world-order. Such reflections lend weight to our definition, for our key claim has been, to repeat, that the metaphysics of science is the metaphysics of order.

## 7. Summary

We began with the observation that, historically, debates within modern metaphysics of science have been centred primarily on issues relating to the natures of kindhood, lawhood, causal power and causation. We went on to suggest an explanation for this, which is that kinds, laws and causation are all what bring *order* to the world, and as such are needed for the very existence of science as we know it. The metaphysics of science is thus concerned with the preconditions of science: the metaphysics of science is the metaphysics of *order*. In the course of arguing for this understanding of the metaphysics of science, we also briefly considered what might demarcate scientific disciplines from non-scientific disciplines. This issue has long been a controversial one, and so for the purposes of this chapter we settled upon a rather minimal demarcation criterion which

says that scientific disciplines are those which are able to deliver systematic predictions (many of which are novel), and explain facts (many of which are new or previously unexplained). With this understanding of science in play, the necessity of kindhood, lawhood and causation for science was highlighted by the point that in a disorderly world (i.e., one void of kindhood, lawhood and causation), it would not be possible to make systematic predictions and provide explanations – that is, to do science.

We then added to the definition proposed by identifying a further key debate within modern metaphysics of science: that concerning the relationship between the various scientific disciplines. We argued that the discipline of metaphysics of science provides the best arena for this debate, because scientists themselves work within, and are therefore constrained by, their own specific scientific disciplines. Moreover, investigating the relationship between the various branches of science is itself part of the project of investigating the nature of the world's order. After adding to our definition in light of this observation, we finally tested the plausibility of our definition by considering whether it clearly marks off debates within the metaphysics of science from other metaphysical debates. After considering some of the core metaphysical debates outside of the metaphysics of science, we suggested that our definition is indeed along the right lines on the basis that these debates are largely independent of the existence and nature of world-order.

## **8. The articles in this volume**

The aim of this volume is to provide a snap-shot of current important research on each of the core topics within the metaphysics of science identified above: the topics of laws, causation and dispositions (or 'powers'), natural kinds, and emergence. Accordingly, the volume is divided into four distinct sections, with each one devoted to each topic. We will conclude this introductory chapter by briefly introducing the main questions and arguments in each paper, and indicating where appropriate how the papers within each section relate to one another.

### **Section 1: Laws**

This section begins with Roberts' 'Measurement, Laws, and Counterfactuals'. The core issue addressed concerns how a certain feature of laws is to be explained. Roberts offers a new answer to this question, and one which will potentially shed light on how it is that scientists are able to draw inferences about laws. Indeed, these two broad themes – that of explaining laws and their features, and that of showing how law inferences are possible – are also main concerns of the other two papers in this section of the volume. Woodward is concerned to shed light on the nature of law (and also causal) inferences, while Lange is concerned with explaining a specific kind of law. As Roberts' paper shows, these two broad themes are not unrelated.

Roberts begins by noting a striking fact about the modal nature of both laws and legitimate measurement methods. The feature in question is that both laws and legitimate measurement



methods are *counterfactually resilient*. What does this mean? Well, to say that a law is counterfactually resilient is to say, roughly, that a genuine law (as opposed, say, to an accidental regularity) is one which holds across a variety of counterfactual suppositions. To say that a legitimate measurement method is counterfactually resilient (as opposed, say, to a method which delivers accurate measurements largely through luck), is to say that such methods deliver accurate measurements across a variety of counterfactual suppositions. But precisely which range of counterfactual suppositions are taken to be the relevant ones? Roberts suggests different people will disagree on this issue. Roberts is not concerned to settle this issue, but claims merely that whatever reasons one has for taking certain counterfactual suppositions to be relevant in the case of laws, those same reasons will also lead one to view the counterfactual resilience of measurement methods in the same way.

What Roberts attempts to establish, then, is that laws and measurement methods are closely connected insofar as they are both counterfactually resilient in the same sorts of ways. Is there an underlying explanation for this connection? Roberts suggests there is, and spends the rest of paper arguing for a novel explanation for this connection.

Roberts' proposal is that the counterfactual resilience of measurement methods is what explains the counterfactual resilience of laws. The pay-off for accepting that the explanation runs in this direction is as follows. The counterfactual resilience of legitimate measurement methods can itself be explained, independently, by facts about epistemic norms concerning the nature of evidence, argues Roberts. Thus the picture Roberts presents is explanatorily rich in that the counterfactual resilience of both laws and (legitimate) measurement methods are explained. But on the alternative picture whereby the counterfactual resilience of laws is taken to be more basic than that of legitimate measurement methods, it is far less clear, according to Roberts, that the counterfactual resilience of the laws will itself be susceptible to a further explanation.

In the second article in the laws section, 'Laws, Causes and Invariance', Woodward is concerned with the kinds of evidential reasoning scientists use to infer laws and causal claims. It is extremely important for metaphysicians to understand how scientific methodology works, Woodward suggests. For this ensures that philosophers do not end up trying to provide metaphysical foundations for non-existent features of science.

The view of laws which is Woodward's starting point is the Lewis-style Best Systems Analysis. As is well known, Lewis develops this theory in the context of his Humean Supervenience thesis, which states that all facts (which will include those concerning laws) supervene on the spatiotemporal distribution of particular matters of fact, each of which are themselves entirely non-modal in nature. On the Best Systems picture, laws consist in the axioms or theorems that occur in the strongest and simplest systemization of the four-dimensional distribution of non-modal facts. In short, the laws capture the most general regularities that occur in a world. Now, according to Woodward, part of the justification for the Best Systems view is that it is supposed to provide a framework which coheres with how law inferences and theory choice in science operate (though in a rather idealised

form). But the picture the Best Systems Analysis presents does not sit well with how science does work, Woodward claims. Woodward concedes, however, that if it is not the case that laws supervene on something like a Humean Supervenience base, it becomes difficult to see how scientists are able to establish laws through empirical testing.

In order to overcome this dilemma, Woodward suggests we must look at how scientists *actually* draw causal and law inferences in a range of scenarios, and use these insights to help develop the metaphysics. This is precisely what Woodward sets about doing in this paper. By studying a range of examples from science, Woodward argues that the Lewisian Best Systems picture (and also the view of causation it lends itself to) is shown to be too simplified. In Woodward's view, inferring laws is not simply a matter of applying criteria like simplicity and strength, nor is the evidential base for law inferences entirely non-modal in character, as Lewis's system suggests. For example, when investigating causal relations and laws, scientists implement intervention and invariance principles. But implementing these principles requires a background of further modal beliefs. We cannot identify a suitable intervention method, for example, unless we already have beliefs about how that intervention will *causally* interact with the experimental elements. More generally, the empirical assumptions which help us to draw causal and law inferences do themselves have causal or nomic import, which suggests that drawing causal and nomic inferences is more complex than the Best Systems Analysis suggests.

In the final paper of the laws section, Lange returns to a general theme, present in the Roberts paper, of explaining laws. Because laws form such a central part of any scientific theory, it is perhaps natural to think that laws – particularly physical laws – are explanatorily fundamental. But we should not be too hasty. We have already seen how Roberts, in the first paper of the volume, suggests that the counterfactual resilience of laws can be explained by further facts. But are physical laws in general ever susceptible to a deeper explanation?

In 'How to Explain Lorentz Transformations', Lange provides us with a case study, and asks whether a certain type of law might have a deeper explanation. The laws in question are those concerning Lorentz Transformations. These laws emerged as a result of Einstein's special theory of relativity and, roughly speaking, Lorentz transformations specify how a point-like event's space-time co-ordinates in one inertial frame maps onto its co-ordinates in another frame. Lorentz transformations play a fundamental role in the special theory of relativity, since it is essentially facts about these transformations which give rise to some of the most well-known and surprising consequences of the special theory, such as the relativity of simultaneity.

Given the fundamental role of Lorentz transformation laws in Einstein's theory, it is perhaps natural to think that they are not themselves susceptible to further explanation. Lange's aim is to question this assumption, though, by exploring what various explanations of Lorentz transformations might look like. Perhaps the nature of Lorentz transformations can be explained in terms of what the fundamental force laws happen to be, for example. Or, more interestingly from a metaphysical

perspective, perhaps an explanation might be available in terms of the very nature of relativity and the geometry of space-time itself.

This latter explanation would be deep indeed, but we cannot expect such an explanation to come easily. For one thing, it will require us to get a grip on how facts about relativity and space-time geometry (and so the Lorentz transformations themselves) can transcend the various force laws. Lange attempts to do just this by showing what such an explanation would be like, with the help of some modal metaphysics. If successful, Lange's proposal has the striking consequence that physical laws – the Lorentz transformations in this case – can, in a certain sense, be explained in a non-dynamic way. Finally, Lange shows how his explanatory strategy might be applied to laws in classical physics, specifically Newton's law.

## Section 2: Causation and Dispositions

In recent decades, disposition-based ontologies have become more and more popular in the metaphysics of science. On such views, at least some of the natural properties of the world are said to be irreducibly dispositional in character, which is to say they are, by their very nature, properties for certain behavioural manifestations. Because of this feature of dispositions, there is clearly a close connection between dispositions and causation. Indeed, Shoemaker, who was one of the first to propose a dispositional view of natural properties, called it the 'causal theory of properties' (1980). More recently, irreducible dispositions are often called causal powers, as is the case in the McKittrick article in this volume.

But what, precisely, is the relationship between dispositions and causation? How does realism about dispositions impact on our understanding of causal talk and of the behavioural mechanisms in the world? Both of the articles in this section of the volume are concerned with these broad questions.

In Huetteman's 'A Disposition-Based Process Theory of Causation', he argues that the dispositional view of properties can help us to find a place for causation in physics. Since Russell's infamous 1912 paper, 'On the Notion of Cause', the concept of causation has been viewed with suspicion, particularly in the philosophy of physics. Russell argued that the concept of causation is too imprecise to be useful in physics, and that the main aims of physics can be carried out perfectly well without invoking causal concepts.

Yet, in spite of Russell's claims, and similar sceptical conclusions from others such as Mach, the notion of causation has continued to be employed pervasively in science – particular in the special sciences. Clearly, then, we need some account of why, at least in some cases, it is natural to frame scientific claims in causal terms. This is essentially Huetteman's aim: to find a place for causation in our scientific world-view, despite Russell's scepticism.

Huetteman begins by motivating the claim that the notion of dispositional properties is needed in physics. Rather than employing purely metaphysical arguments, as some dispositional theorists do, Huetteman motivates the dispositional view by looking at specific examples from physics involving compound systems. We should accept dispositional properties, Huetteman argues, because they

provide the best explanation for the interactions between parts of compound physical systems. These dispositional properties, in turn, serve to ground the very laws governing those physical systems. The main example Huetteman appeals to concerns the interaction between Hamiltonian rotators and oscillators in quantum mechanics.

After outlining his theory of dispositions, Huetteman then suggests how causation might then be understood. Notably, the view Huetteman advocates is not the view that simply sees dispositions as the causes of their manifestations. Although this is perhaps the most obvious way of understanding causation in the context of dispositionalism, Huetteman argues that this simplistic view does not sit well with the examples discussed from physics.

Instead, Huetteman's theory is based on the following central claim: a cause is a disturbing factor which diverts a system away from the behaviour it is naturally disposed to display (what he calls the 'default behaviour'). Since this theory is based on the temporal evolution of systems, it may be classed as a process theory of causation. After developing the details of his view, Huetteman identifies some favourable consequences of the view, compares the theory with other versions of the process theory, and finally discusses some modal implications.

In McKitrick's 'How to Activate a Power' the focus is again realism about dispositions (or what she calls 'powers'). McKitrick's main aim is to explore the relationship between a power, its manifestation, and the 'triggering' circumstances which lead to its manifestation. This relationship has typically been thought to be relatively unproblematic, but McKitrick's new work suggests that dispositionalists may not have understood this relationship as well as they might have assumed.

In her discussion of dispositions and their triggers, McKitrick avoids using causal language. But like Huetteman's view of dispositions, the theories McKitrick discusses have potential implications for a theory of causation. If one takes it that the cause-effect relationship is just the relationship between a power and its manifestation, understanding the precise nature of triggering conditions promises to reveal something important about the nature of causal mechanisms.

McKitrick's starting point is the strongest version of dispositionalism: the view that *all* natural properties are powers (what McKitrick calls 'pan-dispositionalism'). How, McKitrick asks, are we to understand a triggering event if all properties are powers? If events consist in things gaining different properties, as seems plausible, triggering events seem to invite a number of mysteries. For a start, when one considers concrete examples of power manifestation, it is not always clear that a new distinctive power has been brought about during a triggering event. And even in cases where plausible candidates can be found, it is noticeable that those 'triggering' powers can in many cases exist without the manifestation event taking place. This means we then need a further story about what takes us from the instantiation of the 'triggering' power to the final manifestation event. In short, it seems we need a further triggering factor which serves to explain why the initial triggering power is activated. But this, McKitrick highlights, is a regress in the making.

After exploring the precise nature of this regress worry, McKittrick explores a number of possible solutions and draws out their implications. These solutions include the idea that triggering powers do not themselves require further triggers but are, rather, constantly manifesting powers. This solution can also be supplemented with the suggestion that these constantly manifesting ‘triggering’ powers are typically one amongst many other triggering powers all of which must work in conjunction in order to give rise to the final manifestation. After considering some problems facing these proposals, another solution that McKittrick considers involves dropping the assumption that manifestations are always the manifestation of a *single* power only. In the final section, McKittrick summarises what lessons can be learned from her discussion of these various proposals.

### Section 3: Natural kinds

As we saw earlier in this chapter, one of the main aims of science is to categorise nature: that is, to find out what kinds of things there are. This categorisation project is revealed most clearly by the periodic table in chemistry, but natural kind terms are used pervasively in all domains of science. But what precisely are natural kinds? If we were to take scientific talk seriously, it would be natural to suppose that what scientists are doing when they identify kinds is discovering objective divisions that exist in the world: they are ‘carving nature at its joints’. This realist construal of natural kinds also lends itself to the view that each natural kind has its own essence, something in virtue of which it is clearly marked off from other kinds.

But need we take natural kinds as metaphysically seriously as the above remarks suggest? In order to accommodate natural kind talk and the role of natural kinds in science, must we view natural kinds as entities which form an ineliminable ontological category of their own – and as entities with their own distinctive essences? The three papers in this section of the volume all address these general questions. Although each of the three papers approaches the metaphysics of kinds debate in a quite different way, their conclusions all have something in common: they express scepticism about the necessity and feasibility of a strong realism about kinds.

As we saw earlier in this chapter, it was arguably Kripke and Putnam who were the catalysts for the modern debate on natural kinds. They famously argued that theoretical identifications of natural kinds, such as ‘water is H<sub>2</sub>O’, are necessary though knowable only *a posteriori*. This view about the semantics of natural kind terms was then taken by many to go hand in hand with a realist, essentialist view about natural kinds. In Beebee’s ‘How To Carve across The Joints in Nature Without Abandoning Kripke-Putnam Semantics’ she questions whether acceptance of the Kripke-Putnam thesis really does have these strong metaphysical implications. Beebee argues that it does not.

Beebee’s starting point is Salmon’s view about the relationship between the Kripke-Putnam thesis and realist natural kind essentialism. In Salmon’s view, the Kripke-Putnam thesis does not itself justify natural kind essentialism. Rather, a non-trivial essentialist claim has to be presupposed in order to *get* to the necessary *a posteriori* claim about theoretical identities, and it is this that explains why the Kripke-Putnam thesis and essentialism go hand in hand. Crucially, however, this non-trivial essentialist claim is not one that has any of the strong metaphysical implications that

natural kind essentialists typically endorse, argues Beebee. The non-trivial essentialism which Salmon speaks of is, argues Beebee, relatively trivial by most metaphysical lights. And so one can happily accept the Kripke-Putnam semantics without accepting the stronger essentialist view that natural kind classifications somehow carve nature at its fundamental joints.

Beebee's central argument is that the 'non-trivial' essentialist claim which, according to Salmon, is involved in the Kripke-Putnam thesis is not one which rules out there being *cross-cutting* kinds. As Beebee shows, there are number of different senses in which kinds may be said to cross-cutting, but the basic idea is that if kinds cross-cut, there is no single way of carving up nature. To say that kinds cross-cut is to say that there are multiple taxonomic systems which each divide the world in different ways. That is, the categorisations of each system 'cut across' each other. And if none of these ways of dividing the world can have a claim to be more legitimate than any other, the view that science carves nature at its ultimate joints is undermined. Clearly, if the Kripke-Putnam thesis is consistent with this cross-cutting view, as Beebee claims it is, then the Kripke-Putnam thesis does not have the substantive metaphysical consequences many have taken it to have. Beebee concludes her paper by summarising the general implications these results have for the wider essentialist debate.

In Tobin's paper 'Are Natural Kinds and Natural Properties Distinct?', she asks what it could mean for a set of objects to belong to a certain kind, beyond mere facts about which natural properties those objects share. The reason this is an important question is that thoroughgoing realists about natural kinds take it that a *sui generis* category of substantial kinds is needed in our ontology, in addition to the category of properties. Yet, if it were possible to account for talk about natural kinds purely in terms of shared properties, what need would there be for a separate ontological category of kinds? Tobin argues that natural kinds can indeed be understood purely in terms of natural properties, and that views suggesting otherwise are unpersuasive. The upshot is that the robust realist views about natural kinds discussed earlier are undermined.

Tobin begins by exploring the three main ways in which natural kinds might be accounted for in terms of natural properties. The first proposal, which is Lewisian, is one which relies on there being a fundamental distinction between properties which are perfectly natural, and those which are less natural. On this view, two objects are of the same kind insofar as they share the same perfectly natural properties. The second proposal is one which is available to those who take natural properties to be universals, such as Armstrong. On this view, objects are said to be members of the same kind insofar as they instantiate the same conjunctive property universal. The third proposal is Quinean in spirit and trades on the set-theoretic understanding of properties. On this view, two objects are of the same natural kind insofar as they belong to a set whose members share a natural property. Again, this approach trades on the Lewisian distinction between properties which are natural and those which are not. It is this distinction which prevents any set whatsoever from corresponding to a genuine natural kind.

Given the availability of the above strategies, all of which suggest a distinctive ontological category of natural kinds is superfluous, why is it that some metaphysicians of science have nevertheless maintained that a *sui generis* category of natural kinds is needed? It is to this question that Tobin now turns, with the aim of showing that these views about the distinctness of natural kinds face problems.

The main argument in favour of robust natural kind realism which Tobin addresses is the one discussed earlier: the essentialist argument. There are different ways in which essentialists explain the essences of natural kinds, and Tobin examines the main strategies in turn. The first account is one which takes natural kind essences to be universals, the second account takes it that natural kinds possess a sortal essence, and the third account takes it that natural kinds possess a causal essence. Tobin argues that each of these strategies faces problems. This, together with the claim that natural kinds can be accounted for in terms of properties, leads Tobin to conclude that an ontological distinction between natural kinds and natural properties may not be required.

In Paul's 'Realism about Structure and Kinds', she addresses the natural kinds debate, and the realism debate more generally, from the perspective of theories of reference. One thing that has been shown in modern metaphysics of science, in some areas at least, is that metaphysics and the philosophy of language are not unrelated. Let us assume, for example, that metaphysical realism is correct: there is a mind-independent reality and our best scientific theories are objectively true. What precisely does this mean, say, in the case of scientific claims about the natural-kind structure of the world? Well, for one thing, in order for metaphysical realism to hold, it looks like the terms in our theories – natural kind terms in this case – must have a *determinate* reference. For if this were not the case, it would no longer be clear how our natural-kind theories could trace out the objective, natural kind divisions in the world. More generally, it would be difficult to see how any aspect of our theories latches onto a mind-independent world, if reference is indeterminate. Therefore, one way of assessing the feasibility of natural kind realism – and metaphysical realism in general – is to evaluate the claim that reference is determinate.

Paul begins her assessment by outlining the two main theories of determinate reference: the causal theory and the descriptive theory (the causal version of descriptivism being the most promising, according to Paul). Paul suggests that the best overall theory of reference is likely to be one which combines both of these approaches. In the case of fundamental physics, causal descriptivism is most appropriate, according to Paul, though this may not be true of all areas. Since Paul's primary interest is in fundamental physics, she focuses mainly on causal descriptivism for the purposes of this article.

Paul then moves to a discussion of one of the most influential worries concerning realist theories of reference: Putnam's model-theoretic argument. The argument says, roughly, that an (ideal) scientific theory can always be modelled in a way which maps it onto the world in multiple, equally legitimate ways (i.e., ways in which the theory comes out true). On each of these mappings, the terms in the theory will denote different things, and since according to Putnam there is no question of saying which mapping is the correct one, we must accept that reference is radically indeterminate.



After discussing the key assumptions lying behind this objection, Paul discusses the Lewisian response, which trades on the objective samenesses and differences in nature. Paul argues that while this response avoids the conclusion that nearly any interpretation of a scientific theory will make it come out as true, it may still be the case that *more than one* interpretation would make it come out as true. This argument is based on the possibility of what Paul calls the ‘permutability’ of structure and kinds. If permutability is possible in our world, then reference appears indeterminate to some extent, despite Lewis’s insights.

The obvious realist answer, Paul suggests, is to deny that the actual kind-structure of the world happens to be such that it is indeed permutable. But this, Paul argues, weakens the realist’s position significantly, since it makes the success of realism hostage to what look like contingent properties of the world’s structure. Thus, a new important problem has been identified for the realist view.

#### Section 4: Emergence

Some complex natural systems which are the target of scientific investigation are said to be *nonlinear*. To say that a system is nonlinear is to say, broadly speaking, that the overall features and / or behaviours of the system cannot be seen as arising purely out of the additive combinations of the features and / or behaviours of the elements composing the system. For obvious reasons, the discovery of such systems has traditionally been taken to show that a version of the emergentist view of nature (outlined earlier in the chapter) must be correct, at least in the case of some scientific areas.

But precisely what bearing does nonlinearity have on questions concerning emergence? Is nonlinearity always a mark of robust metaphysical emergence, rather than mere epistemological emergence? If so, precisely what kind of metaphysical emergence do cases of nonlinearity suggest? In particular, does such emergence imply the falsity of physicalism, the view that all facts about the world are reducible to physical facts? These are the questions which Wilson addresses in her paper ‘Nonlinearity and Metaphysical Emergence’.

Wilson begins with a historical discussion about how, in the British Emergentist tradition particularly, nonlinearity was taken to be sufficient for strong metaphysical emergence. Strong metaphysical emergence in the British Emergentists’ sense was taken to occur when complex entities or systems could be said to be subject to new laws, laws over-and-above the physical laws governing the components of those entities or systems. Strong emergence in this sense implies the rejection of physicalism, and strikingly, it was thought that the apparent existence of nonlinear systems showed precisely that physicalism is false. As Wilson explains, however, cases of nonlinearity were since discovered which did not plausibly involve new laws (such as population growth for example), suggesting that the traditional account of metaphysical emergence was too strong. Wilson does suggest, though, that it would be beneficial if a more plausible, nuanced definition of strong metaphysical emergence could be formulated, to help us to distinguish between physically



acceptable cases of nonlinearity and cases of nonlinearity which violate physicalism. Wilson concludes the opening section by offering just this.

Wilson then moves on to the contemporary debate about nonlinearity, in particular views which say there are cases of nonlinearity involving properly emergent features or behaviours, but emergence of a kind which is compatible with physicalism (i.e., 'weak' emergence). Wilson argues, however, that none of these views (e.g. those of Newman, Bedau and Batterman) succeed in providing a notion of emergence which is genuinely metaphysical. These accounts of emergence, Wilson argues, are either obviously epistemic from the start, or appeal to cases in which the alleged 'emergent' features could in principle be ontologically reduced, thereby generating a merely representational form of emergence.

Does this mean that we should give up altogether on the prospect of establishing genuine (weak) metaphysical emergence in some cases of nonlinearity? Wilson suggests not, and sets about formulating a new definition of weak emergence which is genuinely metaphysical in nature and yet is compatible with physicalism. The formulation in question is based on the thought that metaphysical emergence involves the elimination of degrees of freedom, which set the parameters needed to describe an entity or system as being in a characteristic state. More precisely, Wilson claims that an entity is weakly emergent if the system out of which it arises has degrees of freedom some of which are eliminated relative to the composing entities. After establishing this formulation, Wilson argues that the emergence involved here is genuinely metaphysical and that, strikingly, there are actual cases of nonlinearity which plausibly have precisely this feature.

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